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THE POSSIBLE PRODUCTION OF LOW ASH AND SULPHUR COAL IN ILLINOIS AS SHOWN BY FLOAT-AND-SINK TESTS

BY

DAVID R. MITCHELL

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BULLETIN No. 258

ENGINEERING EXPERIMENT STATION

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UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

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BY

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THE POSSIBLE PRODUCTION OF LOW ASH AND SULPHUR COAL IN ILLINOIS AS SHOWN BY FLOAT-AND-SINK TESTS

I. Introduction

1. *Historical Background.*—Mechanical cleaning of coal in Illinois was first attempted in 1870 when a washing plant was erected to produce a low ash and sulphur coal for coke-making purposes. In 1883 the first washer was erected to clean coal for fuel, and during the next 40 years there was a more or less steady increase in the amount of coal cleaned for this purpose. The peak year in the production of washed coal was in 1909 and as late as 1912 over three and one-half million tons of coal were cleaned for the market. From that time on there was a steady decrease in amount of coal washed, the number of cleaning plants decreasing from 38 in 1912 to five in 1931.

This decline, to almost the vanishing point, of coal cleaning in Illinois can be attributed to the following causes: the opening up of comparatively clean beds of coal in southern Illinois; the discouraging results obtained in washing the high-sulphur coals to produce a coal low enough in sulphur for metallurgical coke; the limited success obtained in coking Illinois coals; the development of screening practice to produce closely-sized products, which are more efficient than unsized; the inefficiency of the then-existing cleaning plants, particularly in handling the finest sizes; and the development of the mechanical stoker and powdered coal burning equipment which burn successfully coals higher in ash than was possible in the old hand-fired plants.

Engineers during the past 20 years have evidently taken it for granted that high ash coal was a necessary evil, and have expended most of their efforts in perfecting equipment to burn such fuel. As a consequence there has been little or no incentive for the coal mine operator to better or improve his product, so that today Illinois coal is prepared and sold much as it was 20 years ago.

This indifference to coal cleaning is being replaced by real interest. In 1931 a modern coal cleaning plant was erected, the first in a decade, probably marking the beginning of a new era of coal cleaning in Illinois. The various factors which have contributed to this change are: the increased use of mechanical loading equipment, which has

tended to cause an increase in ash and sulphur content, particularly in the finest sizes that cannot be handpicked efficiently; the demands of the consumer for coal of definite specifications to serve a particular purpose; the agitation by city health officials for betterment of smoke and dust conditions, which is causing consumers to demand cleaner coals.

Coal consumers now are not interested so much in the design of new equipment as in the more efficient utilization of the equipment already at hand. They have come to realize that not only are low ash and sulphur percentages desirable, but that uniformity of analysis and size are just as important. Coal operators must meet this demand by a better prepared, clean and standardized coal. Some are already doing so, supplying an exceptional product, and are finding a good demand. For example, the average number of days worked by five Illinois mines, not captive mines, mechanically cleaning their coal or specializing in furnishing a uniform, clean and sized product, was 248 days during 1930, as compared with an average of 145 days for all of the 184 shipping mines in the state. Surely no better reason could be given for the desirability of preparing a clean, uniform coal.

It has been demonstrated repeatedly that there is no economic justification for the marketing of coal containing 10 to 15 per cent of removable impurities. For whatever purpose coal is used, it is to the advantage of the consumer that it contain a minimum amount of ash and sulphur. The presence of incombustible material reduces calorific value, increases the weight that must be handled and transported, gives rise to difficulties of combustion which render the heat less readily available, occasions losses of combustible material through the grates or up the stacks, increases the cost of ash removal, and lessens the strength of coke. The presence of removable sulphur forms may cause excessive slagging and invariably causes excessive corrosion.

The use of clean coal is not only an advantage to the consumer but also to the public at large, since extraneous incombustible material and sulphur increase the production of smoke and irritating gases and the discharge of fine dust from chimney stacks, especially from powdered coal plants. City ordinances regulating the contamination of the atmosphere by smoke, obnoxious gases, and dust from chimneys are becoming increasingly stringent.

Illinois coal producers are faced, at the present time, by two pressing conditions: high cost of production, and the replacement of Illinois coal in its natural markets by cleaner coals of higher calorific value from other states. Although it is desirable that costs be low-

ered as much as possible, yet the production of a clean, uniform coal would do much to offset a small differential in price. Similarly, the higher calorific value of clean coal and the higher efficiencies obtained in burning such a product would aid in reducing the use of coals of higher calorific value from other states.

2. *Object of Investigation.*—Inquiries have become increasingly numerous as to what type of cleaning plant is best for use on Illinois coal, and to what extent these coals could be improved by cleaning processes. As to the first, remarkable progress has been made in developing coal cleaning processes, both in this country and abroad, which can be applied successfully to Illinois coals. It must be realized that there is no type of cleaning process that is applicable to all coals or best under all conditions; but that there is, however, one process or combination of processes that will produce better results for a particular coal than any other process, and that the important factors influencing the selection of a process are those relating to the nature of the coal and its associated impurities. In regard to the extent of beneficiation, exact information is woefully lacking. Very little work has been done in years past which could be used as a guide to determine the relative purity of coal that could be produced from any of the mining districts. The object of this investigation, therefore, has been to determine as completely as possible the purity of coal that could be produced in Illinois, and at the same time to show something of the washability characteristics of these Illinois coals.

3. *Scope of Investigation.*—A broad, general investigation of the washability of Illinois coal was started during the summer of 1931. While it was not possible, because of lack of funds, to sample the various producing districts as completely as was desired, yet all important beds were covered in a broad way. It was necessary to confine the work almost entirely to channel samples, but a few screenings and composite run-of-mine samples were taken. A total of 70 samples have been studied in the laboratory, and in addition all previously reported tests of any value have been included in the discussion or in the comparison summary tables for the various coal beds. These data, so summarized, bring together practically all of the available information relating to the washability of Illinois coals, and should have considerable value to the coal consumer and producer.

It is realized that the data presented herein are not complete and should not be used as a basis for cleaning plant design. Their value

lies in the fact that they partially delineate those areas in the state where clean coal of high purity can be prepared and indicate in a general way the amenability to cleaning processes of a given coal at the locality where sampled.

The late Professor S. W. Parr* of the University of Illinois demonstrated that the pure coal substance for any coal bed within the state was remarkably uniform over wide areas, as shown by the determination of unit B.t.u. values, even though there was a great variation in ash and sulphur percentages. Consequently, the author reasoned that the chief variation in ash and sulphur content of shipped coal was due to variations in the quantity and kind of separable impurities associated with the coal rather than to variations of inseparable impurities in the coal substance. This has been rather forcibly brought out by the data acquired by this investigation. The float coal from the lightest specific gravity solutions shows very uniform ash and sulphur percentages over wide areas. However, there are variations both as to character and amount of separable and inseparable impurities, and to a lesser extent in the pure coal substance. Each mine presents a problem of its own and should be studied by a series of tests such as those outlined by Callen and Mitchell† before a cleaning plant is constructed.

4. *Work of Previous Investigators.*—Studies of the washability of Illinois coals were probably first made and reported by N. W. Lord‡ in 1907. Solutions of calcium chloride were used, and separations made at 1.35 and 1.65 specific gravities. Three samples of coal were crushed to ½-inch and finer before testing, and gave floats at 1.35 specific gravity which analyzed 6.1, 5.7, and 4.8 per cent ash and 3.2, 1.7, and 0.6 per cent sulphur, respectively.

F. C. Lincoln§ made an exhaustive study of coal washing in Illinois, and used zinc chloride solutions of 1.35 specific gravity to determine washery efficiency. Float at 1.35 specific gravity on a sample of 1¼-in. washed screenings from No. 2 coal, northern Illinois, analyzed 7.1 per cent ash. The float from four samples of ¼-in. washed screenings from No. 6 coal, southern Illinois, analyzed 4.7, 4.6, 4.1, and 4.7 per cent ash, respectively.

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*"Purchase and Sale of Illinois Coal on Specification," Illinois State Geological Survey Bulletin 29, 1914.

†"Washability Tests of Illinois Coal," Univ. of Ill. Eng. Exp. Sta. Bul. 217, 1930.

‡"Experimental Work Conducted in the Chemical Laboratory of the United States Fuel-Testing Plant at St. Louis, Missouri," U. S. Geological Survey Bulletin 323, 1907. Reprinted as U. S. Bureau of Mines Bulletin 28, 1911.

§"Coal Washing in Illinois," Univ. of Ill. Eng. Exp. Sta. Bul. 69, 1913.

E. A. Holbrook* made a further detailed study of the preparation of Illinois coal for the market, and made some float-and-sink studies of eleven samples of screenings, using zinc chloride solutions of 1.35 specific gravity. As received, the eleven samples varied in ash from 6.72 to 24.88 per cent, and in sulphur from 0.90 to 7.16 per cent. The float-and-sink tests showed that a large part of the screenings was good coal of from 4.22 to 8.74 per cent ash and 0.6 to 3.5 per cent sulphur, with recoveries ranging from 63.70 to 92.50 per cent.

These results are valuable in that they clearly show that it is possible to produce a very low ash coal with high recoveries from a number of the producing districts. They are incomplete in that no consideration was given to the moisture problem as it affects specific gravity recoveries, and many of the analyses are given without reference to the state of the sample,—as received, air dried, or dry. Also, there are not enough data to determine anything as to the ease or difficulty of cleaning these coals.

Fraser and Yancey† pioneered on this problem of coal washability in the United States. Most of their work was done in the years 1918 to 1924 at the University of Illinois in the Laboratory of the Department of Mining Engineering. They were probably the first investigators in this country to demonstrate the value of a detailed washability analysis of coal made by dividing it up into a number of fractions by use of a series of solutions of different specific gravities. They published complete float-and-sink data on certain sizes of three Illinois coals which are included in the tables of comparison summaries of all mines tested.

Callen and Mitchell‡ enlarged on these testing methods, worked out a procedure for making a complete study of the washability of all the sizes produced by a given mine, and made such studies of the washability characteristics of coal from seven mines located in five different counties.

The work of these last two groups of investigators clearly showed the great variation in washing characteristics of Illinois coals, ranging from those very easy to clean through stages of increasing difficulty to those that can scarcely be beneficiated by modern processes under present economic conditions. In all of the publications mentioned complete data are available for only seven mines, although fragmentary data, as shown, are given for several more. All of this prior

*"Dry Preparation of Bituminous Coal at Illinois Mines," Univ. of Ill. Eng. Exp. Sta. Bul. 88, 1916.

†"Cleaning Tests of Central Illinois Coal," U. S. Bureau of Mines Technical Paper 361, 1925. "Coal Washing Investigations, Methods and Tests," U. S. Bureau of Mines Bulletin 300, 1929.

‡Op.Cit.

work, together with an ever-increasing demand for more detailed information on the washability and degree of purity of coal that could be obtained by cleaning processes, indicated the great need for further information of this kind for Illinois coals.

5. *Acknowledgments.*—The work was performed as part of the regular program of the Engineering Experiment Station of the University of Illinois, and has been under the administrative direction of Dean M. S. Ketchum, and of Prof. A. C. Callen, Head of the Department of Mining Engineering.

The work was in charge of the author who was assisted in the laboratory and in the preparation of data by Mr. H. E. Gross, Research Graduate Assistant in Mining Engineering. Mr. J. W. Appling, Professor of Chemistry, Mackenzie College, Sao Paulo, Brazil, on leave of absence for work in the Department of Mining Engineering at the University of Illinois, assisted in the laboratory. Prof. G. L. Clark, of the Department of Chemistry, courteously furnished facilities for the taking of radiographs.

Appreciation is also expressed for the aid extended by state mine inspectors and mine operating officials in obtaining samples.

II. Test Procedure

6. *Sampling Methods.*—A modified form of the United States Bureau of Mines standard method of face sampling of coal mines was adopted. In brief, a channel approximately 8 inches wide and 4 inches deep was cut from top to bottom of the bed with *nothing* excluded. These samples of from 25 to 150 pounds each, depending on the height of coal sampled, were sealed in lard cans and shipped to the laboratory.

As a check on the premise that the pure coal substance was uniform without reference to the extraneous impurities present, a mine was sampled in Vermilion County that was known to have a very irregular distribution of impurities. A room was picked at random and the place of sampling selected by the sampler walking to the face with eyes shut and making a mark. At this place sample No. AK52 was taken. Moving to the right and leaving 12 inches of coal, sample No. AK53 was taken. Figure 1 shows the detailed columnar sections of the coal at these two places sampled.

Figure 2 is a view of the face after these samples were taken, showing both channels cut and one sample on the sampling cloth in the foreground. One of the lard cans used as a container for shipping

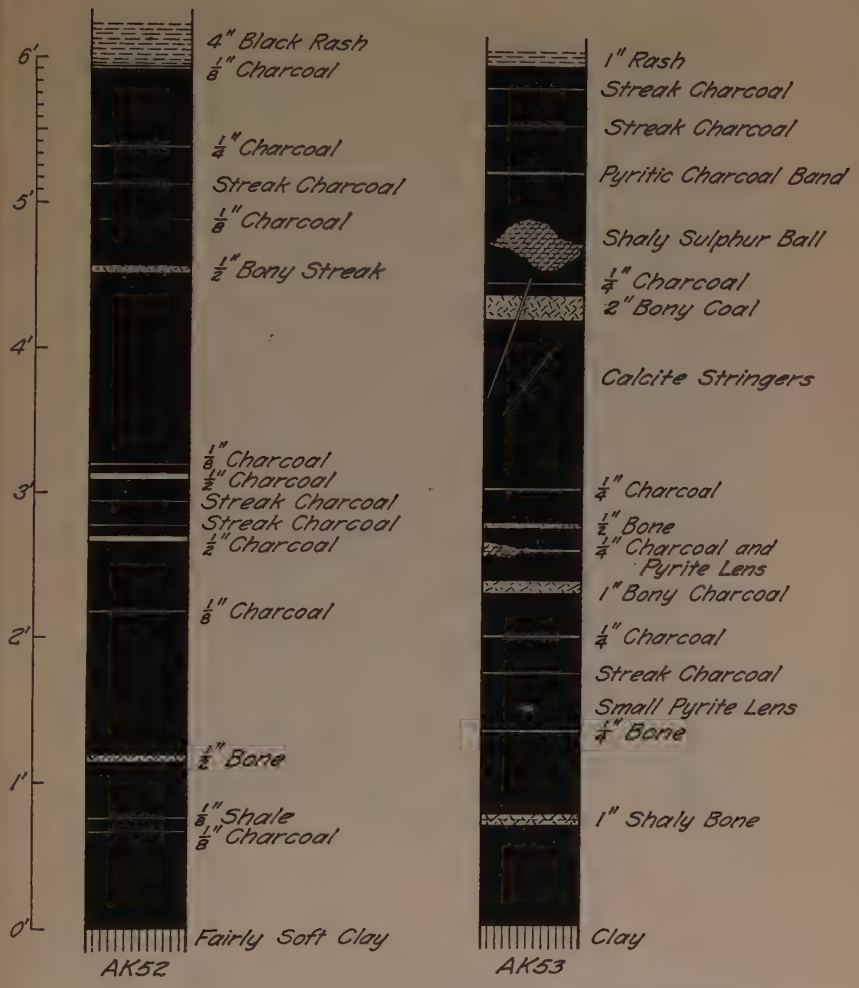

Fig. 1. Face Sections of No. 7 Coal, Vermilion County

samples to the laboratory is also shown in this photograph. The apparent deviation of these channels from the vertical is due to the camera being not quite level and not squarely in front of the slightly convex coal face.

Referring to the float-and-sink data, it is to be noted that, while these samples contained 9.9 and 16.8 per cent ash, respectively, the 1.30 specific gravity float fractions contained 2.6 and 2.7 per cent ash, respectively. This close agreement on the amount of ash in the purest coal fraction is duplicated in the sulphur percentages, which

FIG. 2. COAL FACE AFTER BOTH SAMPLES WERE CUT

are 3.1 and 7.2 per cent for the complete channel samples and 2.4 per cent for each 1.30 specific gravity float fraction. Furthermore, this close agreement in the uniformity of the mineral content of the pure coal substance has been checked a number of times on different coals and generally holds true over wide areas, provided always that check determinations are made on coal crushed to the same size. Apparent variations from this general rule for coal from the same mine or locality are usually due to a lack of appreciation of the effect of crushing on the liberation of impurities and separation of one coal constituent from another.

Face samples taken by the United States Bureau of Mines Standard Method* in which all impurities thicker than $\frac{3}{8}$ inch are excluded,

*"The Sampling of Coal in the Mine," U. S. Bureau of Mines Technical Paper No. 1.

might show a much closer agreement in ash and sulphur percentages for the total channel samples. Nevertheless, no very close agreement could be expected in sampling this mine by the standard method because of the great amount of thin bands and flakes of impurities. Channel samples cut by the standard method give a fair indication of the quality of the larger sizes of Illinois coal, if the mines are operated by hand-loading methods and the coal is cleaned by hand picking. There is no such criterion for machine-loaded coal. Previous experience* in sampling Illinois coals by the modified method as described herein indicates that such samples give results that correspond closely to the nut sizes, while the egg and lump sizes are lower in ash, and the finest sizes (⅛-inch and finer) are higher.

The intermittent working of the mines during the summer of 1931 made it impossible to obtain channel samples in every case so that three types of samples were taken, as follows:

(1) Channel; a channel sample was cut from a fresh face, top to bottom of the mining height, approximately 8 inches wide and 4 inches deep, with nothing excluded. It was then sealed in lard cans and shipped to the laboratory.

(2) Screenings; a sample was taken by standard methods from chutes, bins, or railroad cars. Approximately 200 pounds were taken, mixed, and quartered down to 50 pounds for shipment to the laboratory in sealed cans.

(3) Run-of-Mine; this type of sample was taken from mine cars or bins, when it was not possible to obtain any other kind. A 200- to 300-lb. sample of coal, as representative as possible under the conditions encountered, was crushed by hammers, mixed, and quartered to about 50 pounds for shipment to the laboratory in sealed cans.

Throughout this bulletin, the same letter or group of letters, except for the GR samples, indicates the mine from which the sample was taken. The numerals following the letter give the sample numbers. It has not been possible to give the identity of mines or exact locations where samples were taken, since most operators have asked that such information be withheld from published data. However, the uniformity of cleaned Illinois coal over wide areas is so marked that mine operators in any county can arrive at a close approximation of the degree of purity of coal that can be produced, and the ease or difficulty of cleaning such coal, by a study of the data given for the particular coal bed in which they are interested.

*"Washability Tests of Illinois Coals," Univ. of Ill. Eng. Exp. Sta. Bul. 217, 1930.

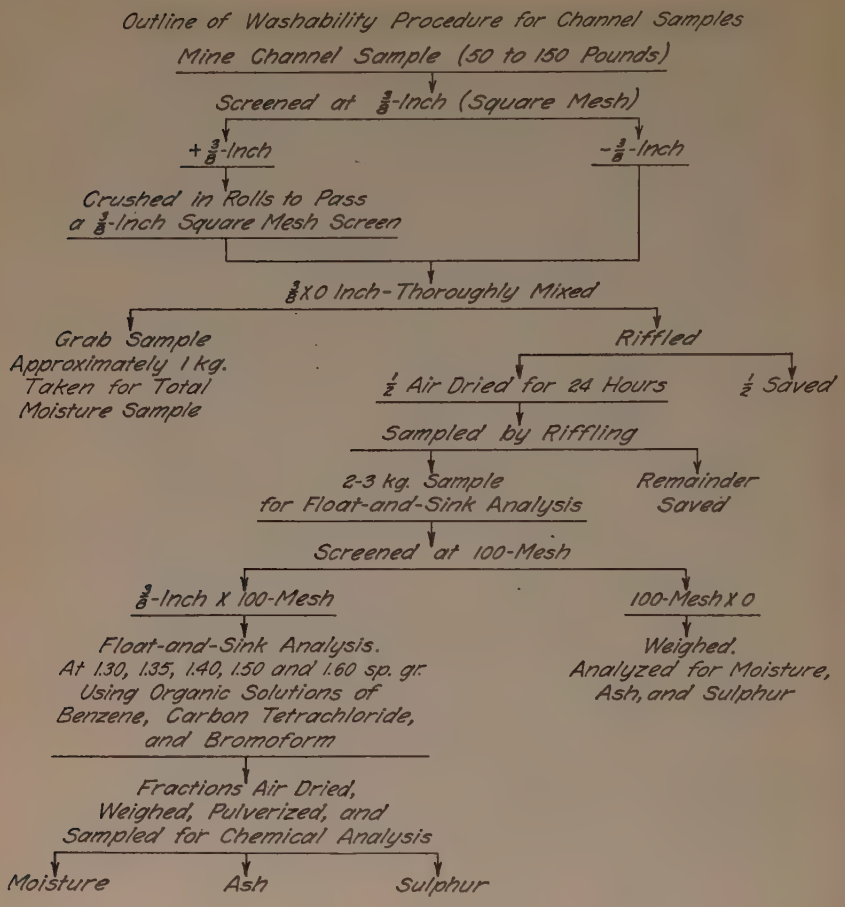
Outline of Washability Procedure for Channel Samples
Mine Channel Sample (50 to 150 Pounds)
Screened at ⅜-Inch (Square Mesh)
+⅜-Inch
-⅜-Inch
Crushed in Rolls to Pass a ⅜-Inch Square Mesh Screen
⅜ X 0 Inch-Thoroughly Mixed
Grab Sample Approximately 1 kg. Taken for Total Moisture Sample
Riffled
½ Air Dried for 24 Hours
½ Saved
Sampled by Riffling
2-3 kg. Sample for Float-and-Sink Analysis
Remainder Saved
Screened at 100-Mesh
⅜-Inch X 100-Mesh
100-Mesh X 0
Float-and-Sink Analysis. At 1.30, 1.35, 1.40, 1.50 and 1.60 sp. gr. Using Organic Solutions of Benzene, Carbon Tetrachloride, and Bromoform
Weighed. Analyzed for Moisture, Ash, and Sulphur
Fractions Air Dried, Weighed, Pulverized, and Sampled for Chemical Analysis
Moisture
Ash
Sulphur

Fig. 3. Flow Sheet

7. *Float-and-Sink Procedure.*—All samples were subjected to the same standardized procedure in the laboratory. Figure 3 is a flow sheet of the laboratory procedure for all channel samples and the few run-of-mine samples taken. The samples of screenings were not crushed prior to float-and-sink analysis, otherwise the procedure was the same.

All samples were dedusted at 100-mesh prior to float-and-sink analysis. This dust was weighed, sampled, and analyzed for moisture, ash, and sulphur. Chemical analyses of these dusts showed them to be higher in ash and sulphur percentages than the corresponding samples subjected to float-and-sink analysis.

The dust was removed from all samples because of the difficulty of making accurate float-and-sink separations when it was present. The amount of dust obtained varied from 1 to 4 per cent of the samples, so that no serious error in the float-and-sink analysis of samples resulted from its removal.

Organic solutions were used entirely. For specific gravities of 1.60 and above, solutions of carbon tetrachloride and bromoform were used. Solutions lighter than 1.60 specific gravity consisted of mixtures of carbon tetrachloride and benzene.

Solutions of 1.30, 1.35, 1.40, 1.50, and 1.60 specific gravities were used in this investigation. For Illinois coals the fractions above 1.60 specific gravity seldom contain much combustible material. In practically all of the coals tested the 1.60 specific gravity sink analyzed at least 50 per cent ash. Those few coals that contained a sink fraction at this gravity analyzing less than 50 per cent ash were given an additional treatment at 2.0 specific gravity to further delineate the character of the coal.

8. *Interpretation of Data.*—Sufficient data are presented for all samples so that anyone interested can construct washability curves. Bulletin 217 of the Engineering Experiment Station, University of Illinois, contains complete information on the methods of calculation, manner of construction, and interpretation of washability curves.

Complete float-and-sink data are calculated and tabulated so that washability curves can be constructed, and also to show the yields and analyses of products at selected specific gravities as given in the comparison summary tables. While it is true that these separation points are somewhat arbitrary, yet for the purpose of comparing the several coals they are quite logical. The names assigned to the three separation products—clean coal, middlings, and refuse—are expressive of the character of these products.

To be consistent, and for comparison purposes, all results are given on a moisture-free basis so that the percentages of ash and sulphur are somewhat higher than if given on an as-mined or as-received basis.

A method* proposed by B. M. Bird, based on the amount of intermediate specific gravity material at the cleaning gravity, has been used for comparison purposes. This method is based on fundamental properties of coal in that it recognizes the fact that the presence of particles slightly heavier and slightly lighter than the specific gravity at which separation is desired complicates the separation. Fortun-

*"Interpretation of Float-and-Sink Data," Proceedings Second International Conference on Bituminous Coal, Pittsburgh, Pennsylvania, 1928. Proceedings Third International Conference on Bituminous Coal, Pittsburgh, Pennsylvania, 1931.

ately, for purposes of comparison, Illinois coals are reasonably similar and theoretical data indicate that most of these coals should be cleaned at specific gravities ranging from 1.40 to 1.70, with an average of about 1.50. The data in the comparison summary tables are so tabulated that the amount of ± 0.10 specific gravity material at 1.50 specific gravity can be read from them. This ± 0.10 specific gravity material is designated *middlings* in the comparison summary tables and is that part of the sample which floats at 1.60 specific gravity and sinks at 1.40 specific gravity. Using Bird's terminology, the following figures are used to show roughly the ease or difficulty of cleaning:

Per Cent ± 0.10 Sp. Gr. Material at 1.50 Specific Gravity	Degree of Difficulty	Preparation
0–6.4	Simple (S)	Almost any process; high tonnages.
6.5–9.2	Moderately Difficult (MD)	Efficient processes; high tonnages.
9.3–14.0	Difficult (D)	Efficient processes; medium tonnages; good operation.
14.1–18.0	Very Difficult (VD)	Efficient processes; low tonnages; expert operation.
18.1–22.5	Exceedingly Difficult (ED)	Very efficient processes; low tonnages; expert operation.
Above 22.5	Formidable (F)	Limited to a few exceptionally efficient processes; expert operation.

The key letters in parentheses are used in the comparison summary tables to classify the various samples.

These figures differ from those used by Mr. B. M. Bird in that they have been calculated to compensate for sink below about 2.0 specific gravity, which has no effect on the ease or difficulty of cleaning. This classification is useful for comparison purposes, but must only be used with a full realization of its limitations. The size of coal tested may show considerable variation in the amount of ± 0.10 specific gravity material present so that, even for coal from the same mine, one size may fall in one classification and another size in another. Also, it is often desirable to clean different sizes at different specific gravities, which means that comparisons must be made of the amount of ± 0.10 specific gravity material present at the cleaning gravity for each size. The same generalization holds true in comparing two different coals. In any case ± 0.10 specific gravity distribution curves should be constructed for exact comparison purposes. Furthermore, this method, being purely theoretical, does not take into consideration the effect of size or shape on the efficiency of the coal cleaning operations. Fine sizes of coal may appear to be a simple

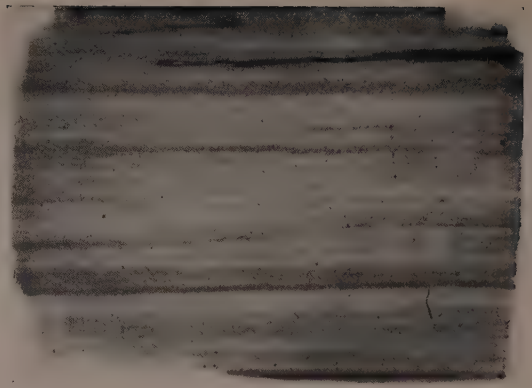

FIG. 4. RADIOGRAPH OF PRACTICALLY PURE COAL

FIG. 5. RADIOGRAPH SHOWING PYRITE BAND IN COAL

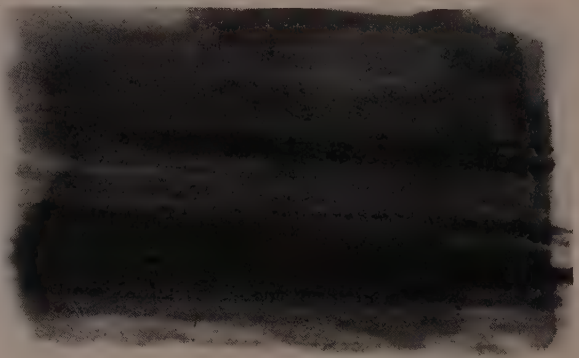

FIG. 6. RADIOGRAPH SHOWING SHALE BANDS IN HIGH ASH COAL

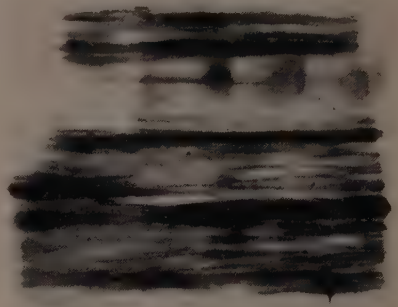

FIG. 7. RADIOGRAPH SHOWING INTERSTRATIFIED COAL, SHALE AND PYRITE BANDS

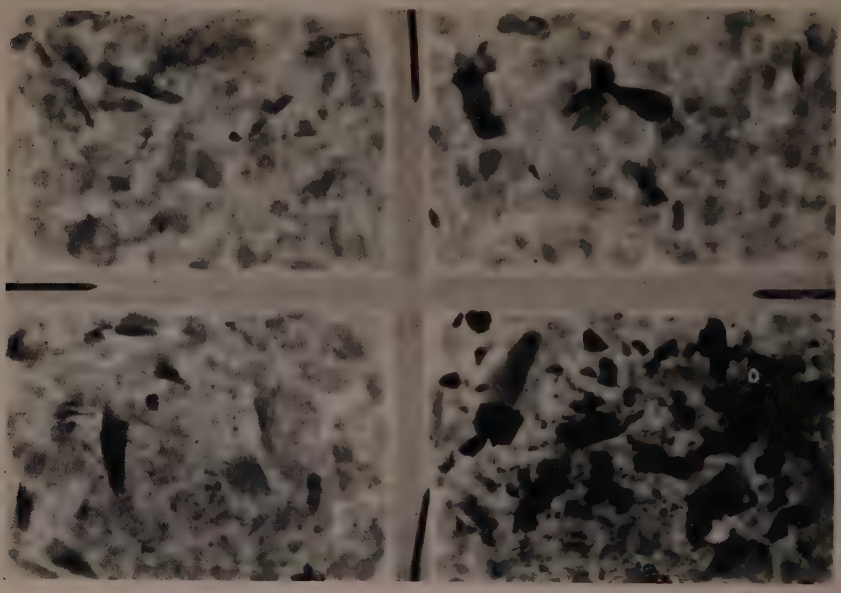

FIG. 8. RADIOGRAPH OF CHANNEL SAMPLES

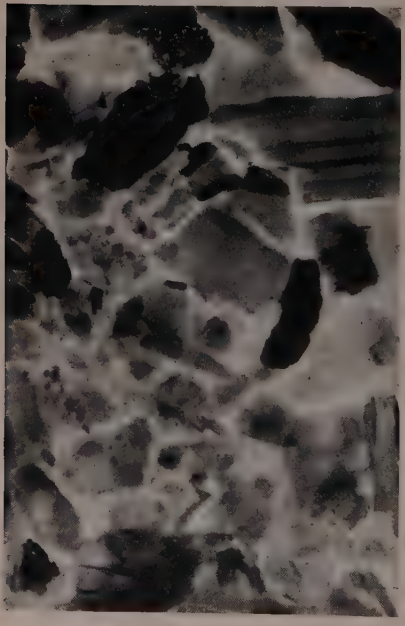

FIG. 9. RADIOGRAPH OF F8 SCREENINGS

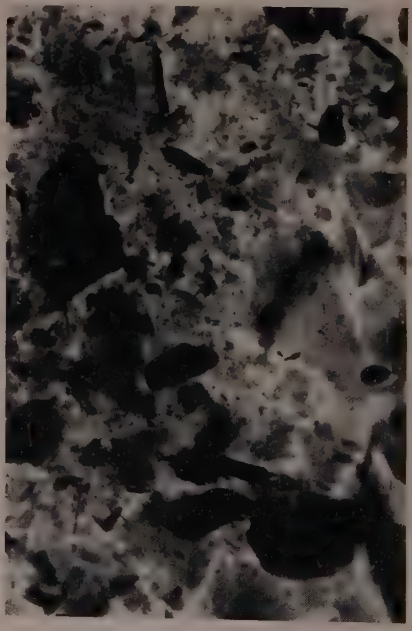

FIG. 10. RADIOGRAPH OF V30 SCREENINGS

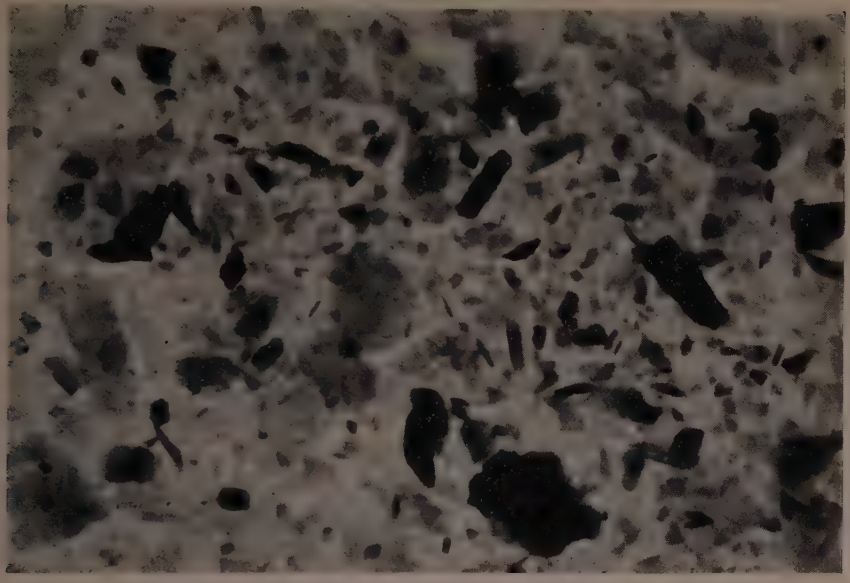

FIG. 11. RADIOGRAPH OF RAW SCREENINGS

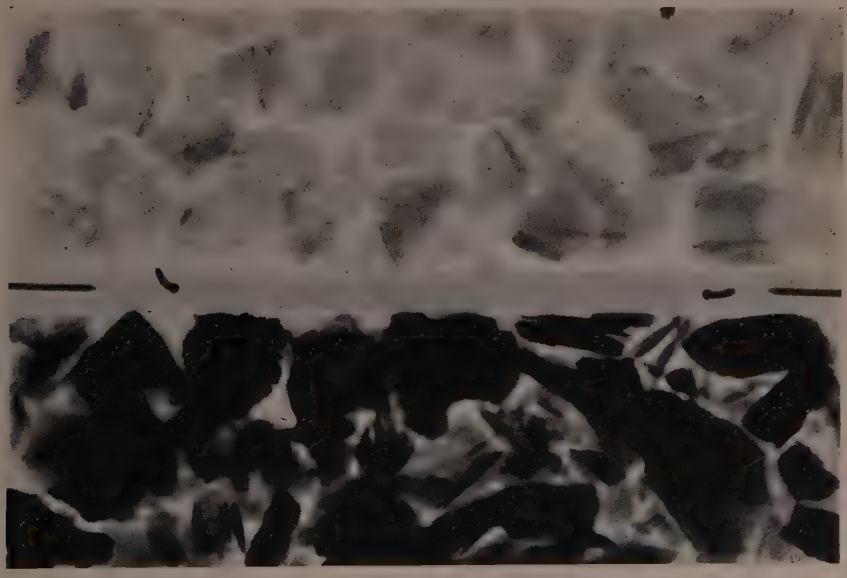

FIG. 12. RADIOGRAPH OF FLOAT-AND-SINK SEPARATION AT DESIRED SPECIFIC GRAVITY

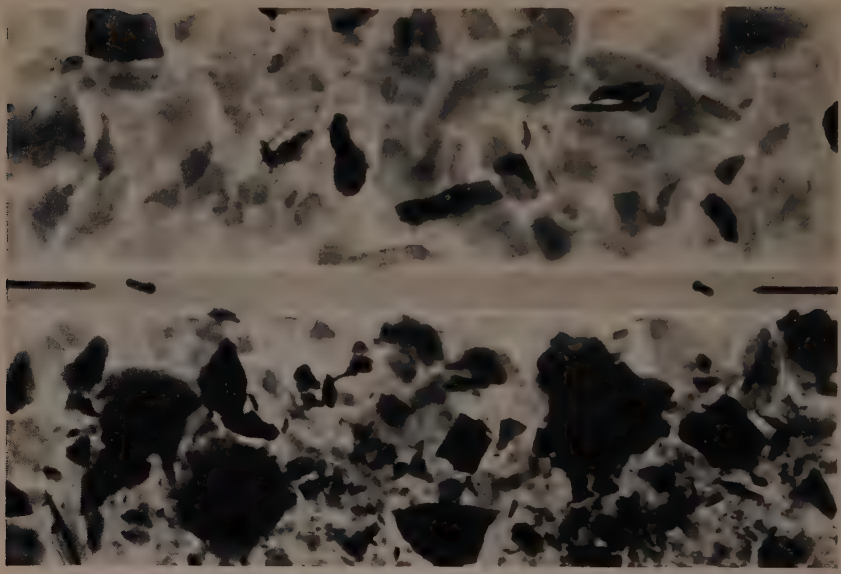

FIG. 13. RADIOGRAPH SHOWING IMPERFECT CLEANING

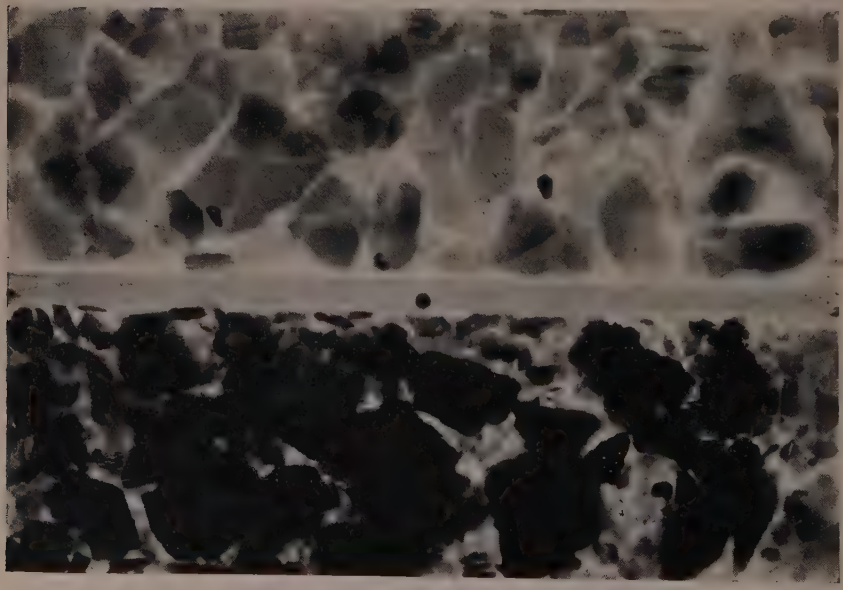

FIG. 14. RADIOGRAPH SHOWING EFFICIENT CLEANING

cleaning proposition by the ± 0.10 specific gravity distribution curve, yet they are always difficult to clean by any process. Nevertheless this method has considerable merit, and provides a simple, easy, and reliable way of comparing washability characteristics of coals.

The coal beds have been named according to the terminology employed by the Illinois State Geological Survey. Since some confusion exists as to the proper correlation of beds the county is always given, and in some cases the local name of the bed.

9. *X-ray Examination.*—X-rays are of great value in studying the characteristics of coal and associated impurities, particularly so in illustrating something of the purity of a given coal and its amenability to cleaning processes. Pure coal is nearly transparent to X-rays, while the common impurities, such as shale, clay, pyrite and calcite, are relatively opaque. Therefore, in an X-ray photograph of a lump of coal, the pure coal substance resembles a block of dirty ice, and any mineral impurities present show up as dark to black spots or bands in much the same way as bones stand out in a radiograph of the human body. The purer the coal substance exposed to X-rays the fewer rays will be absorbed and the lighter the photograph will be. As the mineral matter content increases more X-rays will be absorbed and the photograph will be relatively darker, provided of course that the test procedure is kept the same throughout. Bands, lenses, and veins of mineral impurities absorb all or nearly all of the rays and hence show up as dark to black markings on the photographs. Impurities consisting of elements of high atomic number absorb more of the X-rays than do those made up of elements of low atomic number. Thus a pyrite band of the same thickness as a shale band is always much darker. Not only is it possible to differentiate between coal and mineral impurities, but it is also possible to tell something of the size and nature of the coal constituents and of the associated mineral impurities.

One of the aggravating problems in preparation is that of determining whether or not a given coal, sized or unsized as the case may be, carries separable or inseparable mineral impurities. Visual inspection can only be applied to the largest sizes and even then has a limited application. Chemical analysis alone does not give the answer. It is only through long series of float-and-sink tests, crushing, and chemical analysis that authoritative information can be obtained. The use of X-rays offers a possible solution of problems of this kind since all impurities can be seen in bold relief whether attached or unattached to the coal. Also, information is easily and quickly ob-

tained as to whether impurities are of such a size and nature that crushing will liberate them. Furthermore, the samples are not destroyed and can be used for other tests if desired.

Figure 4 is an X-ray photograph of a nearly pure lump of coal containing a few thin streaks of shale. The typical banded structure of Illinois coal can be seen with the bright coal showing up as the lighter bands and the dark coal as the darker ones. Except for the few streaks of shale present, shown by thin, black bands at the top of the photograph, this sample contains only inseparable mineral matter which is a part of the coal substance. Such mineral matter is usually referred to as *inherent*, that is, a natural part of the coal substance. Figure 5 shows a pyrite band surrounded by bright coal of low ash content, and stringers or veinlets of pyrite extending from the main pyrite band into the coal substance. Veinlets of this character have been mentioned by Briggs and Kemp* as evidence that the mineral salts, such as pyrite, were exuded from the coal into cracks in the coal and deposited, rather than that such mineral inclusions were deposited from underground waters, according to the accepted theory. The upper part of this specimen shows a band of coal very high in inherent ash. Figure 6 is a radiograph of a specimen of high ash coal, as shown by its dark color, containing slightly pyritiferous shale bands. These bands could probably be freed by crushing but the ash content of the coal substance would still be high. Figure 7 shows a lump consisting of thin bands of coal, shale and pyrite. Flakes of pyrite and calcite are also present. Coal so intimately mixed with mineral impurities is usually known as "bony" coal or simply as "bone," and would require a great reduction in size by crushing before any freeing of coal from impurities would result.

X-rays are not only of value in studying individual pieces of coal, but are also useful when studying sized or unsized samples *en masse*. Radiographs were made of a number of the channel samples upon which float-and-sink tests were made, the size of the coal being $\frac{3}{8}$-in. x 100 mesh. These samples were placed in small wooden boxes and exposed to the X-rays according to a standard procedure. Wood is even more transparent to X-rays than coal so that there is no interference caused by such containers intercepting the X-rays.

Figure 8 is a radiograph of grab samples of four of these channel samples. The percentage of ash, sulphur, and 1.60 specific gravity sink, given in the order named, for the samples is as follows:

AO 48..... 9.8, 0.8, 5.0	AH 49.....10.1, 1.1, 5.3
AJ 51.....10.7, 1.4, 5.8	AK 53.....16.8, 7.2, 19.5

*"A Note on the Mineralogy of Coal as Suggested by X-ray Examination." Transactions of the Institute of Mining Engineers, 77, 5, 1930.

It is interesting to note in comparing these values with what can actually be observed in the photographs, that it is not only possible to judge roughly the comparative amounts of free impurities present, but also the relative ash and sulphur percentages of these samples.

Radiographs may also be of great value in studying commercial sizes of coal. X-ray photographs of closely sized coal are much easier of interpretation than those of unsized samples, and conclusions arrived at from the former are more accurate. However, a wealth of information can be obtained from radiographs of unsized coal samples. Figures 9 and 10 are comparative studies of 1½-in. screenings samples of coals, F8 and V30. By referring to the data, the reader can readily see the value of making comparison studies of this kind when determining the washability characteristics of different coal samples. In the F8 sample the free impurities are mostly large, which means a simple cleaning problem. Some of the coal particles contain thin streaks of impurities, and this raises the question as to whether or not it would be desirable to make a middling product in cleaning this coal for the market. These screenings are much cleaner than the V30 screenings.

The V30 screenings show a great amount of free impurities, pyrite and shale in all sizes, so that any attempt to raise the grade by screening out the very finest sizes would probably be unsuccessful. More pyrite is present in V30 than in F8, as shown by the intense blackness of the impurities. The irregular veinlets in some of the coal particles in the F8 sample are due to calcite and not to pyrite or shale.

The use of X-ray photographs need not be limited to a study of coal in the raw state. They can also be used as an adjunct to the study of float-and-sink fractions in determining visually the character of intermediate specific-gravity fractions, and thus furnish a clue as to the feasibility of crushing these products to free impurities. Coal radiography is a great aid to the accepted methods of coal testing (chemical analysis and float-and-sink testing) so that it is probable that the future will see few coal cleaning plants erected without a previous use of this new tool for coal research.

Coal radiography may also be used effectively to show the efficiency of existing cleaning plants, and should prove a valuable adjunct to the usual procedure of float-and-sink testing and chemical analysis of cleaning plant products. A series of radiographs illustrating results obtained in cleaning a coal in the laboratory is given in Figs. 11 to 14, inclusive. Figure 11 is a radiograph of coal No. AM55, which is a 1½-in. screenings sample from a mine working the No. 6 coal bed in Sangamon County. Float-and-sink tests were made, as reported in

the table of results for this coal bed. Screenings tests were also made, and with this evidence supporting conclusions drawn from the radiograph, that the impurities were freely distributed throughout all sizes, a cleaning gravity was selected and the minus $\frac{3}{16}$-in. fines removed for separate treatment. A float-and-sink separation of this $1\frac{1}{2}$ x $\frac{3}{16}$-in. size was made at the desired cleaning gravity, as shown by Fig. 12. Cleaning tests were then made by two different processes. Figure 13 is a radiograph of the products obtained in cleaning this coal by a process which was inefficient, despite all efforts to jockey the cleaning plant to a high degree of efficiency. The quantitative efficiency by Drakeley's formula in this case was 93.0 per cent. Not only can refuse particles be seen in the cleaned coal, but a considerable amount of good coal is present in the refuse.

In cleaning this same coal by another process quite different results were obtained, as shown by Fig. 14. This process made an almost perfect separation, with a quantitative efficiency of 99.8 per cent. The high efficiency of this process can also be observed by comparing Figs. 12 and 14, the radiograph for the actual cleaning test being little different from that for the theoretical float-and-sink cleaning test.

The foregoing examples and discussions cover only a few of the possible applications of X-rays in coal research. No special equipment is needed other than is found in the usual X-ray laboratory used by the medical profession. Facilities for this method of analysis are thus available in the towns and cities in practically all of the coal producing districts.

However, a thorough knowledge of the nature of coal and of the occurrence of mineral impurities is necessary for the proper interpretation of X-ray photographs. Certain precautions must also be observed. The procedure to be followed must be standardized as to intensity of X-rays, distance of specimens from the target of the tube, time of exposure, and developing and printing methods. Lump specimens should be of the same thickness for comparison purposes. The thinner the specimen the more accurately will impurities be shown in their true proportion. The lump specimens of Figs. 4 to 7 were $1\frac{1}{2}$ inches thick. The specimens should be exposed so that the X-rays pass parallel to the bedding planes. This is not possible in subjecting boxes of a number of pieces of coal to the X-rays. Not all particles will be placed so that the rays will pass parallel to the bedding planes, and as a consequence a thin band of mineral impurity may cloud an otherwise nearly pure particle of coal. However, any investigator

with a knowledge of these limitations can acquire a great amount of reliable information quickly, easily, and at low cost.

Examinations and comparisons are best made between negatives themselves, since there is a better range of tone values than on the printed radiographs.

In this investigation the X-ray tube used was of the Coolidge type, operated at 85 kilovolts and 5 milliamperes. All specimens were exposed for ¼ second and placed at a distance of 66 centimeters from the target of the X-ray tube.

III. Tests on Samples from the Various Coal Beds

10. *Results Obtained from Coal Beds No. 1 and No. 2.*—Coal bed No. 1 is the oldest, geologically speaking, of any economic importance mined in the state. It occurs in the Pottsville formation, and is locally called the "Rock Island," "Assumption," or "Seville No. 1" coal depending upon the locality where mined. Sample No. R26 (Rock Island) was the only one obtained from this bed.

It has the least economic importance of the coal beds discussed in this bulletin because of its irregular occurrence and the great depth at which it lies over most of the Illinois coal basin. These conditions make any extensive mining operations impractical. It is important locally, occurring in lens-shaped masses, two to five feet thick, of limited lateral extent. It is mined chiefly around the fringes of the Illinois coal basin where the Pottsville formation is found close to the surface. Information is lacking as to its occurrence throughout the main body of the coal basin since drilling is not usually carried to the depth at which the Pottsville formation lies.

At the mine sampled, the impurities were thin bands and lenses of pyrite, slate, and bone. Some mineral charcoal was present along the bedding planes, and flake pyrite and calcite along the vertical cleavage faces of the coal. The roof rock is usually limestone, and the floor rock a medium-hard, sandy shale. Mining conditions are, therefore, good where the coal is of a workable thickness, with very little liklihood of extraneous impurities from the roof and floor being introduced during mining operations.

Tables 1 and 2 give the laboratory data for this coal. It presents only a moderately difficult cleaning problem. A clean coal of very low ash content could be obtained, although sulphur elimination is only partially successful so that a clean coal of less than about three per cent sulphur content could not be produced.

Table 1

Float-and-Sink Results—Coal Beds Nos. 1 and 2

Per cent by Weight and Per cent Ash and Sulphur in Fractions at Different Specific Gravities
(Moisture Free)

Sample Number	County	Coal Bed	<1.30 Sp.Gr.			1.30–1.35 Sp.Gr.			1.35–1.40 Sp.Gr.			1.40–1.50 Sp.Gr.			1.50–1.60 Sp.Gr.			>1.60 Sp.Gr.			Total		
			Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S
R26	Fulton	1	54.4	2.7	2.5	21.2	7.0	3.5	6.3	11.1	4.7	7.0	17.7	8.2	1.7	23.5	10.4	9.4	48.4	18.1	100.0	9.8	4.9
F8	Will	2	67.1	3.8	1.2	12.9	4.7	1.8	5.9	7.2	2.3	2.0	18.9	5.6	1.4	31.2	8.6	10.7	67.3	7.2	100.0	11.6	2.2
F9	Will	2	59.0	1.7	0.5	34.1	2.5	0.6	1.4	10.0	1.9	1.1	17.9	4.6	0.5	29.4	9.2	3.9	53.3	14.1	100.0	4.4	1.2
F10	Will	2	72.4	2.7	1.5	21.4	4.1	2.1	2.3	8.1	4.3	1.0	13.2	6.5	0.2	22.2	10.2	2.7	60.3	9.7	100.0	4.8	2.0
G11-1	Henry	2	55.0	5.1	3.0	18.9	9.1	4.4	9.5	12.6	6.5	5.7	17.7	8.8	1.6	27.3	10.7	9.3	51.8	19.4	100.0	12.0	5.6
G11-2	Henry	2	52.5	5.5	2.9	22.4	10.1	4.2	7.9	13.7	6.2	5.2	18.4	8.1	1.4	30.4	11.6	10.6	52.1	22.0	100.0	13.1	5.9
G12	Henry	2	16.9	4.0	3.0	32.0	6.0	3.3	23.0	10.3	5.1	12.1	14.3	7.7	5.1	20.8	9.4	10.9	53.9	15.6	100.0	13.6	5.8
I14	LaSalle	2	50.0	3.1	2.3	25.9	6.3	3.0	7.0	12.2	4.0	4.3	18.9	5.5	2.3	21.7	7.1	10.5	55.1	26.1	100.0	11.1	5.3
S27	Fulton	2	75.9	3.0	2.3	11.1	5.8	3.8	2.8	7.7	5.2	2.2	11.7	8.4	2.4	15.3	10.7	5.6	40.1	17.7	100.0	6.0	3.7
AC37	Saline	2	42.3	4.3	2.4	31.5	8.1	3.1	7.0	12.2	4.9	5.5	15.7	7.7	2.4	21.8	13.2	11.3	54.6	34.6	100.0	12.8	7.0

Coal bed No. 2 is the next coal in geologic age that is of any economic importance. It occurs at the base of the Carbondale formation, and is characterized by its remarkable uniformity as to thickness throughout the Illinois coal basin. It varies from two to five feet in thickness with a known average of about 42 inches over wide areas. Constituting at one time the principal source of Illinois coal production, it dropped rapidly in importance with the development of mining operations in the thicker beds of coal in central and southern Illinois. It is, however, of considerable economic importance at the present time with mines operating in this bed located chiefly around the northern, western, and southern edge of the Illinois coal basin.

Some of the purest coal produced in Illinois is obtained from this bed, and in general it can be stated that it is usually fairly free from extraneous impurities and of a better quality than coal existing at higher geologic horizons in the same district. The common impurities are pyrite, shale, and calcite, which in most of the samples tested broke freely from the coal substance. Considerable mineral charcoal and some bony coal was noted in some of the samples.

Samples of coal from this bed in the northern part of the Illinois coal basin showed pronounced slacking tendencies in the float-and-sink solutions. Wet cleaning of these coals would probably cause a considerable amount of degradation of the larger pieces because of this tendency.

The roof is usually a soft shale or soapstone and the floor a rather soft clay. These rocks weather easily and get mixed with the coal to some extent whether mining is carried on by open-pit, room-and-pillar, or longwall methods. These shale impurities from the roof and floor or from shale bands in the coal are more friable than the coal substance so that there is a concentration of them in the finest of the market sizes. For this reason screenings are usually much higher in ash than the larger prepared sizes. These shale impurities also resemble clay in that they go into suspension rather easily in water, thus further complicating the wet cleaning of these coals, particularly as to water clarification. Both the friability and the ease of weathering of these impurities decrease toward the southern part of the Illinois coal basin until they are hard and slate-like with no tendency to form suspensoids or colloids in water. For example, sample No. AC37 from Saline county gave a sink at 1.60 specific gravity which was hard and firm, showing no signs of disintegration in the solutions.

Table 1 gives complete float-and-sink data for all samples tested in the laboratory. The unusually low ash percentages for the 1.30 specific gravity floats show that for the sizes tested the purest coal is remarkably free from mineral impurities.

Table 2

Comparison Summary of Float-and-Sink Results—Coal Beds Nos. 1 and 2

Per cent by Weight and Per cent Ash and Sulphur in Clean Coal, Middlings, and Refuse
(Moisture Free)

Sample Number	Type of Sample	Coal Bed	County	Coal Bed Moisture per cent	Clean Coal <1.40 Sp.Gr.			Middlings 1.40–1.60 Sp.Gr.			Refuse >1.60 Sp.Gr.			Total			Probable Degree of Difficulty of Cleaning at 1.50 Sp. Gr.
					Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	
R26	Channel	1	Fulton	13.3	81.9	4.5	2.9	8.7	18.8	8.6	9.4	48.4	18.1	100.0	9.8	4.9	MD
F8	1½-in. screenings	2	Will	17.1	85.9	4.2	1.4	3.4	24.0	6.8	10.7	67.3	7.2	100.0	11.6	2.2	S
F9	Channel	2	Will	19.0	94.5	2.1	0.6	1.6	21.5	6.1	3.9	53.3	14.1	100.0	4.4	1.2	S
F10	Channel	2	Will	16.1	96.1	3.1	1.7	1.2	14.7	7.1	2.7	60.3	9.7	100.0	4.8	2.0	S
G11-1	Channel	2	Henry	17.1	83.4	6.9	3.7	7.3	19.8	9.2	9.3	51.8	19.4	100.0	12.0	5.6	MD
G11-2	Channel	2	Henry	17.0	82.8	7.5	3.6	6.6	21.0	8.8	10.6	52.1	22.0	100.0	13.1	5.9	MD
G12	1½-in. screenings	2	Henry	15.7	71.9	6.9	3.8	17.2	16.2	8.2	10.9	53.9	15.6	100.0	13.6	5.8	VD
I14	Channel	2	LaSalle	13.4	82.9	4.9	2.7	6.6	19.9	6.1	10.5	55.1	26.1	100.0	11.1	5.3	MD
S27	Channel	2	Fulton	13.4	89.8	3.5	2.6	4.6	13.6	9.6	5.6	40.1	17.7	100.0	6.0	3.7	S
AC37	Channel	2	Saline	5.6	80.8	6.5	2.9	7.9	17.6	9.4	11.3	54.6	34.6	100.0	12.8	7.0	MD
USBM*	1-in. x 48 mesh	2	Marshall	14.0†	79.7	6.0	2.1	4.9	25.2	6.4	15.4	80.3	5.7	100.0	18.4	2.8	S‡
USBM	1-in. x 2-in.	2	Marshall	14.0†	92.2	6.0	2.2	2.6	23.7	9.7	5.2	76.3	6.2	100.0	10.1	2.6	S‡
E	5 x 0-in.	2	LaSalle	12.4	82.3	8.7	3.9	6.3	26.1	8.7	11.2	57.6	15.8	100.0	15.2	5.6	S¶

*Tipple sample of screenings 1-inch x 0-inch taken for float-and-sink analysis. The dust (48 x 0 mesh) was removed before testing. This dust amounted to 21 per cent of the sample and contained 22.7 per cent of ash.

†Average obtained from published analyses.

‡Bulletin 300, United States Bureau of Mines.

¶Bulletin 217, Engineering Experiment Station, University of Illinois.

Table 2 shows these same data calculated to selected specific gravities for comparison purposes. In addition, data for three samples are included from other publications. Comparative data for a total of twelve samples are given, seven of which can be classed from the specific gravity analyses as simple, four moderately difficult, and one very difficult to clean. In general, this coal wherever mined is comparatively easy to beneficiate by cleaning processes, although, as previously mentioned, the character of the impurities may further complicate the cleaning problem. The data indicate that a low ash coal with high recoveries could be obtained from nearly all of the mines sampled, and a product moderately low in sulphur from those mines located in Will county.

11. *Results Obtained from Coal Bed No. 5.*—This coal bed occupies an intermediate position in the Carbondale formation which begins at the base of No. 2 coal, extending through No. 5 coal to the top of No. 6 coal. Where mined, No. 5 coal varies in thickness from four to eight feet, with an average over a great area of the state of from five to six feet. Although of uniform thickness over wide areas, it shows considerable variation in the character of coal and associated impurities. It has the usual banded appearance of Illinois coal with bright coal predominating in some mines and in others, dark coal.

The chief impurities present in the samples tested were bands, lenses and streaks of bone, pyrite and shale. Most of the samples contained some flake calcite. Mineral charcoal containing a high percentage of impurities was present in a number of samples, constituting four or five per cent of the total sample in some cases. These impurities were all irregular in occurrence, and any one of them might cause a difficult cleaning problem at one mine and be of only minor importance at another mine in the same district.

In addition to these impurities, numerous clay veins or "horsebacks," varying from a streak to several feet in thickness, are found extending from the roof down through the coal bed to the floor. Spar "horsebacks," which are veins of pyrite or marcasite filling cracks in the coal at angles varying from nearly horizontal to the vertical, are common in some districts. It is not uncommon for the "horsebacks" to have veinlets and stringers extending for several inches into the surrounding coal.

The roof and floor are usually firm, and give little trouble during mining operations by getting mixed with the coal. The immediate roof material is usually a black shale several inches in thickness, containing nodules or "niggerheads." In some counties this black

Table 3

Float-and-Sink Results—Coal Bed No. 5

Per cent by Weight and Per cent Ash and Sulphur in Fractions at Different Specific Gravities
(Moisture Free)

Sample Number	County	<1.30 Sp.Gr.			1.30–1.35 Sp.Gr.			1.35–1.40 Sp.Gr.			1.40–1.50 Sp.Gr.			1.50–1.60 Sp.Gr.			>1.60 Sp.Gr.			Total		
		Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S
J1-15	Livingston	74.7	5.1	3.0	8.7	9.2	3.7	5.0	13.9	4.4	3.9	20.2	5.0	1.4	32.7	8.4	6.3	55.0	20.2	100.0	10.0	4.0
K17	Livingston	44.4	5.1	2.3	21.2	10.3	2.9	13.5	16.1	2.5	11.8	23.5	2.8	2.7	29.2	4.9	6.4	58.5	8.9	100.0	13.9	3.0
M19	Peoria	33.1	7.1	2.7	42.5	11.8	2.7	11.3	17.9	2.6	3.8	23.9	2.5	2.3	27.8	2.3	7.0	52.2	5.0	100.0	14.6	2.8
N20	Peoria	12.9	4.4	2.4	41.1	8.8	2.6	22.3	13.5	3.1	12.9	17.8	4.9	4.0	24.8	5.7	6.8	40.5	8.1	100.0	13.2	3.5
N21	Peoria	20.1	4.1	2.4	48.0	7.2	2.7	15.1	11.3	3.3	8.9	15.6	5.5	2.3	21.0	8.7	5.6	46.2	14.5	100.0	10.4	3.8
O22	Peoria	37.2	5.4	2.3	35.6	10.4	2.4	12.5	16.3	3.4	4.8	22.8	5.0	2.4	29.2	6.0	7.5	43.5	6.4	100.0	12.8	3.0
Q25	Fulton	47.0	5.3	3.0	21.2	9.8	3.8	13.7	13.7	6.0	9.3	18.0	9.4	3.1	23.6	11.0	5.7	48.7	19.5	100.0	11.6	5.4
T28	Tazewell	34.2	5.5	2.7	40.7	9.6	3.0	9.7	13.5	4.9	3.5	18.7	6.7	2.4	26.5	7.5	9.5	63.5	8.9	100.0	14.4	3.9
U29	Tazewell	50.3	5.7	2.7	31.4	9.7	2.9	7.7	14.3	3.7	3.4	19.1	5.3	1.2	25.3	5.1	6.0	42.8	6.2	100.0	10.5	3.2
V30-1	Macon	18.1	4.7	2.9	36.3	7.0	3.0	18.2	12.1	3.6	8.5	18.3	4.6	2.7	27.7	5.0	16.2	71.3	6.7	100.0	19.4	3.9
V30-2	Macon	14.4	4.2	2.8	40.1	6.4	2.8	17.4	12.1	3.4	10.2	18.4	4.4	3.2	27.7	4.9	14.7	71.8	4.9	100.0	18.6	3.4
W30A	Logan	7.7	4.8	2.6	45.8	7.2	2.9	22.9	12.2	3.8	11.0	17.3	5.8	3.6	25.3	8.2	9.0	63.7	7.7	100.0	15.0	4.0
W30B	Logan	37.7	4.7	2.4	36.3	7.7	2.5	13.7	12.8	2.8	6.4	18.2	5.4	1.3	25.6	6.2	4.6	42.9	1.6	100.0	9.8	3.2
Y32	Sangamon	33.3	3.8	2.8	40.7	8.4	3.1	8.6	14.4	4.1	7.7	20.1	6.3	2.8	27.8	8.2	6.9	49.6	15.8	100.0	11.7	4.4
Z33	Menard	18.7	4.0	3.1	35.7	6.5	3.2	19.1	11.6	4.2	12.0	16.6	6.8	4.5	23.2	10.3	10.0	50.4	17.7	100.0	13.4	5.6
AN40	Gallatin	37.4	4.5	2.5	39.2	9.0	2.8	10.0	13.6	4.3	4.6	17.5	6.3	1.3	22.0	10.8	7.5	52.3	31.4	100.0	11.6	5.2
AE41	Saline	33.1	3.5	1.8	47.9	7.4	2.0	8.0	12.2	3.2	4.1	17.7	5.2	1.6	21.4	9.1	5.3	58.5	18.7	100.0	9.8	3.2
AE42	Saline	43.3	3.1	1.5	41.0	7.2	1.8	7.4	20.0	2.7	3.9	22.6	6.7	1.2	22.7	6.8	3.2	54.0	20.6	100.0	8.7	2.6
AE43	Saline	47.3	3.1	1.6	35.1	7.0	2.3	7.8	12.2	3.4	3.6	16.9	4.9	0.8	21.9	7.0	5.4	52.2	33.1	100.0	8.5	3.8
AF44	Saline	41.9	3.4	1.6	43.3	6.3	2.0	7.5	10.4	3.3	3.1	14.7	5.7	0.8	21.5	10.5	3.4	54.6	16.8	100.0	7.4	2.6

shale acts as a draw slate, contaminating the coal and further complicating the cleaning problem.

The presence of the clay veins and the "niggerheads" in the black shale roof are the common criteria for identification of this bed, although the clay veins are not especially characteristic of this coal in Saline and Gallatin counties, as they are throughout the central, western and northern part of the Illinois coal basin. The clay in these veins is usually soft and disintegrates easily in water.

This coal bed is locally called the "Harrisburg," "Springfield," "Rushville" or "Blair No. 5" coal. It usually presents a more difficult cleaning problem than the No. 2 coal, as shown by the float-and-sink analyses. In addition, the ash and sulphur percentages of the lightest fraction are somewhat higher, although it is possible in some areas to produce a coal of very low ash content. It is not possible to prepare a cleaned coal very low in sulphur by any known coal cleaning process from any of the mines at which samples were taken. It is possible, however, to prepare a product containing two per cent sulphur or less at those mines in Saline county from which samples were taken. There is also the possibility that there are other mines in this same county or district at which the coal could be cleaned to a still lower sulphur content. Furthermore, there are numerous mines working this bed in various sections of the state which were not sampled, and vast areas of undeveloped coal land containing the No. 5 bed which might contain coal of low sulphur content.

Table 3 gives the detailed data of the specific-gravity analyses of the coals tested, while Table 4 gives the float-and-sink data calculated for purposes of comparison to show recoveries and ash and sulphur percentages at selected specific gravities.

A number of the samples gave a sink at 1.60 specific gravity which analyzed less than 50 per cent ash. A visual inspection of this sink revealed that in all cases the low ash percentage was due to large amounts of mineral charcoal, impregnated with pyrite or calcite, and bone coal. These samples were re-run at a specific gravity of 2.0 in order to further delineate the character of this 1.60 specific gravity sink. The following additional data were obtained for these samples:

Sample Number	1.60–2.0 Sp.Gr.			>2.0 Sp.Gr.		
	Wt. per cent	Ash per cent	Sulphur per cent	Wt. per cent	Ash per cent	Sulphur per cent
N20	4.2	34.2	2.4	2.6	65.8	10.8
N21	2.5	31.1	9.1	3.0	55.6	16.5
O22	4.0	34.5	3.9	3.5	53.8	9.3
Q25	2.2	32.1	9.0	3.5	59.2	26.1
U29	3.7	32.0	3.1	2.3	60.2	11.2
W30B	2.5	34.9	6.6	2.1	52.4	17.6

TABLE 4

COMPARISON SUMMARY OF FLOAT-AND-SINK RESULTS—COAL BED NO. 5

Per cent by Weight and Per cent Ash and Sulphur in Clean Coal, Middlings, and Refuse
(Moisture Free)

Sample Number	Type of Sample	County	Coal Bed Moisture per cent	Clean Coal <1.40 Sp.Gr.			Middlings 1.40–1.60 Sp.Gr.			Refuse >1.60 Sp.Gr.			Total			Probable Degree of Difficulty of Cleaning at 1.50 Sp.Gr.
				Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	
J15	Run-of-mine	Livingston	12.1	88.4	6.0	3.1	5.3	23.5	5.9	6.3	55.0	20.2	100.0	10.0	4.4	S
K17	Run-of-mine	Livingston	11.4	79.1	8.4	2.5	14.5	24.6	3.2	6.4	58.5	8.9	100.0	13.9	3.0	VD
M19	Channel	Peoria	15.2	86.9	10.8	2.7	6.1	25.4	2.4	7.0	52.2	5.0	100.0	14.6	2.8	S
N20	Channel	Peoria	15.0	76.3	9.5	3.0	16.9	19.5	5.1	6.8	46.3	5.6	100.0	13.7	3.5	VD
N21	Channel	Peoria	15.0	83.2	7.3	3.2	11.3	16.7	6.1	5.5	44.5	13.1	100.0	10.4	4.1	D
O22	Channel	Peoria	14.5	85.3	9.1	2.5	7.2	24.9	5.3	7.5	43.5	6.4	100.0	12.8	3.0	MD
Q25	Channel	Fulton	15.8	81.9	7.9	3.7	12.4	19.4	9.8	5.7	48.7	19.5	100.0	11.6	5.4	D
T28	1½-in. screenings	Tazewell	13.7	84.6	8.4	3.1	5.9	21.9	7.0	9.5	63.5	8.9	100.0	14.4	3.9	S
U29	Run-of-mine	Tazewell	12.4	89.4	7.8	2.9	4.6	20.7	5.2	6.0	42.8	6.2	100.0	10.5	3.2	S
V30-1	1½-in. screenings	Macon	14.1	72.6	7.7	3.1	11.2	20.6	4.7	16.2	71.3	6.7	100.0	19.4	3.9	D
V30-2	1½-in. screenings	Macon	14.1	71.9	7.3	2.9	13.4	20.6	4.5	14.7	71.8	4.9	100.0	18.6	3.4	MD
W30-A	1½-in. screenings	Logan	13.9	76.4	8.5	3.1	14.6	19.3	6.4	9.0	63.7	7.7	100.0	15.0	4.0	VD
W30-B	Channel	Logan	14.2	87.7	7.2	2.5	7.7	19.5	5.5	4.6	42.9	11.6	100.0	9.8	3.2	MD
Y32	Channel	Sangamon	15.8	82.6	7.2	3.1	10.5	22.2	6.8	6.9	49.6	15.8	100.0	11.7	4.4	D
Z33	Channel	Menard	13.8	73.5	7.2	3.4	16.5	18.4	7.8	10.0	50.4	17.7	100.0	13.4	5.6	VD
AN40	Channel	Gallatin	4.2	86.6	7.6	2.8	5.9	18.5	7.3	7.5	52.3	31.4	100.0	11.6	5.2	S
AE41	Channel	Saline	7.4	89.0	6.4	2.0	5.7	18.7	6.3	5.3	58.5	18.7	100.0	9.8	3.2	S
AE42	Channel	Saline	7.3	91.7	6.3	1.7	5.1	22.6	6.7	3.2	54.0	20.6	100.0	8.7	2.6	S
AE43	Channel	Saline	7.3	90.2	5.4	2.0	4.4	17.8	5.3	5.4	52.2	33.1	100.0	8.5	3.8	S
AF44	Channel	Saline	7.9	92.7	5.3	1.9	3.9	16.1	6.7	3.4	54.6	16.8	100.0	7.4	2.6	S
AP	5-in. x 0-in.	LaSalle	12.3	83.7	9.1	3.5	9.6	26.9	4.6	7.7	57.3	18.8	100.0	14.6	5.0	D*
AQ	⅛-in. x 0-in.	LaSalle	12.3	59.2	5.2	3.1	15.6	15.2	3.7	25.2	66.1	8.3	100.0	22.1	4.5	VD*
C	6-in. x 0-in.	Peoria	16.5	84.8	14.0	3.3	9.0	32.6	5.6	6.2	60.7	7.5	100.0	18.5	3.8	MD*
H	2-in. lump crushed to 1-inch	Peoria	15.6	84.6	8.2	3.9	3.2	14.1	8.1	3.2	43.4	16.0	100.0	10.4	4.8	S*
G	6-in. x 0-in.	Williamson	7.6	82.8	8.9	3.8	10.7	22.3	8.5	6.5	56.1	13.2	100.0	13.4	4.9	D*

*Bulletin 217, Engineering Experiment Station, University of Illinois.

These data can be substituted for the 1.60 specific-gravity sink data in the tables by any one desiring to construct washability curves for these coals to this higher specific gravity.

Ten of the twenty-five samples listed in the comparison summary tables can be classed as simple, four as moderately difficult and five as very difficult to clean. Screenings from mines operating in this coal bed are usually higher in ash and sulphur than the larger prepared sizes. This is due in some cases to the presence of friable shale or clay from the roof, floor, or clay veins getting mixed with the coal. At other mines, it is because the impurities exist as thin bands, veinlets, or flakes which break freely from the coal substance and concentrate in the fine sizes.

12. *Results Obtained from Coal Bed No. 6.*—This coal is the most important, economically, worked in the state. It is found over the greater portion of the Illinois coal basin varying in thickness, where mined, from three to fourteen feet, with an average thickness of five to eight feet over large areas. It occurs at the top of the Carbondale formation, and is identified nearly everywhere by a persistent band of dark shale known as the "blue band." This shale band is found from six to twenty-four inches above the floor of the coal and varies in thickness from a streak to as much as six inches. This bed may further be identified by the fact that it is normally divided up into three separate benches. The bottom bench is separated from the middle bench by the "blue band," and in turn the middle bench is separated from the top one by a persistent band of mineral charcoal which may carry considerable pyrite in the high sulphur areas. In the Danville district only two benches are found, separated from each other by the "blue band."

This coal bed in some districts may be identified by a persistent bed of limestone above the coal. It is found immediately over the coal throughout the greater part of the coal fields in southwestern Illinois. At places, it is separated from the coal by a few inches of black slate and elsewhere by a gray shale which may be as much as forty feet in thickness. This limestone is absent in the Danville district and in parts of southern Illinois. Where absent, the roof material is usually a gray shale that weathers easily causing poor roof conditions. Some mines leave up top coal in order to prevent contamination of coal by falls of roof rock and to insure better roof conditions.

The other chief structural feature of this bed that is of interest from the standpoint of the cleanability of the coal is the presence of

TABLE 5

FLOAT-AND-SINK RESULTS—COAL BED NO. 6

Per cent by Weight and Per cent Ash and Sulphur in Fractions at Different Specific Gravities
(Moisture Free)

Sample Number	County	<1.30 Sp.Gr.			1.30–1.35 Sp.Gr.			1.35–1.40 Sp.Gr.			1.40–1.50 Sp.Gr.			1.50–1.60 Sp.Gr.			>1.60 Sp.Gr.			Total		
		Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S
B3	Vermilion	56.6	5.5	1.8	19.8	10.2	2.3	7.0	15.6	2.8	4.6	21.5	3.5	2.9	32.2	3.7	9.1	56.6	5.6	100.0	13.3	2.4
D5	Vermilion	64.3	4.6	0.9	13.0	9.8	1.1	5.2	14.2	1.5	7.7	20.5	1.9	2.1	31.5	2.6	7.7	66.4	4.2	100.0	12.3	1.3
L18	Stark	50.0	4.1	2.3	23.7	7.2	3.6	7.8	13.2	5.2	4.3	19.5	5.6	3.2	29.7	5.8	11.0	58.6	16.5	100.0	13.0	4.7
Q24	Fulton	37.5	5.5	3.9	37.2	8.7	4.2	14.9	12.7	5.5	6.6	16.4	8.0	1.1	25.6	8.3	2.7	58.4	16.2	100.0	10.1	4.9
X31	Sangamon	36.7	4.4	3.6	31.7	8.9	4.1	9.3	13.3	4.9	8.2	19.1	5.5	3.1	27.6	6.0	11.0	59.0	22.4	100.0	14.6	6.2
AA34	Christian	40.3	4.4	3.8	24.9	7.6	4.1	14.1	11.9	4.8	9.4	17.8	5.7	3.2	23.7	8.2	8.1	46.7	21.5	100.0	11.6	5.8
AB35	Macoupin	37.7	4.0	4.7	23.0	5.6	4.3	16.1	10.1	4.6	10.2	16.1	6.5	3.2	23.8	7.9	9.8	57.9	14.4	100.0	12.5	5.8
AB36	Macoupin	50.9	3.7	4.4	21.1	7.0	4.2	8.8	12.4	4.4	5.3	17.7	5.7	2.1	26.3	7.0	11.8	63.0	19.2	100.0	13.4	6.2
AC38	Saline	41.1	3.7	2.5	37.4	9.3	2.5	11.2	14.9	2.8	5.4	19.5	4.0	1.2	24.2	6.5	3.7	59.7	17.0	100.0	10.2	3.2
AD39	Gallatin	41.1	3.7	2.3	28.3	8.7	2.7	10.9	13.5	3.2	5.3	17.7	5.2	2.1	21.2	7.4	12.3	60.1	26.2	100.0	14.2	5.7
AG45	Franklin	61.7	2.8	1.1	21.3	8.4	1.1	6.3	14.3	1.3	4.4	21.3	1.3	1.8	31.3	1.9	4.5	65.1	3.6	100.0	8.9	1.2
AG46	Franklin	57.1	2.8	0.7	26.5	7.2	0.7	6.9	13.5	0.6	3.6	20.8	0.6	1.0	32.5	0.7	4.9	65.6	1.5	100.0	8.7	0.7
AO47	Franklin	56.8	3.7	0.8	22.1	9.3	0.8	7.1	14.9	0.8	3.5	21.0	0.9	1.8	27.9	1.2	8.7	61.1	3.8	100.0	11.8	1.1
AO48	Franklin	54.6	2.9	0.8	23.0	8.2	0.8	9.1	14.3	0.8	4.5	21.2	0.8	3.8	28.4	0.8	5.0	59.6	1.7	100.0	9.8	0.8
AH49	Franklin	58.4	3.0	1.0	23.2	8.7	1.0	7.1	14.9	1.0	3.6	21.7	1.0	2.4	29.6	1.1	5.3	71.3	1.9	100.0	10.1	1.1
AH50	Franklin	49.7	2.8	1.0	27.1	8.6	1.2	8.7	15.2	1.2	4.5	22.4	1.7	3.2	27.9	1.8	6.8	63.9	5.1	100.0	11.3	1.4
AJ51	Jackson	51.0	3.8	1.0	26.8	8.6	1.3	8.3	14.7	1.2	4.8	20.9	1.2	3.3	26.6	1.4	5.8	58.1	5.0	100.0	10.7	1.4
AL54	Christian	51.2	5.9	3.8	14.6	8.0	3.8	10.9	13.4	4.8	9.1	18.7	6.1	2.2	29.7	8.1	12.0	61.8	17.1	100.0	15.4	5.8
AM55	Sangamon	64.6	6.2	3.4	9.0	11.5	4.1	6.3	14.9	4.5	5.4	20.4	5.3	1.7	29.0	7.1	13.0	65.6	10.7	100.0	16.1	4.6
GR5	St. Clair	50.0	5.0	3.3	22.4	9.6	3.4	7.5	14.0	3.4	5.9	19.5	3.3	3.4	27.5	3.0	10.8	64.1	14.1	100.0	14.7	4.5
GR7	Clinton	26.9	4.0	3.7	29.3	6.0	3.6	18.6	11.2	3.7	11.3	17.0	4.1	4.2	23.5	5.1	9.7	50.1	15.0	100.0	12.7	4.9
GR10	Macoupin	19.5	4.4	4.4	27.4	6.4	4.5	15.8	10.5	4.7	14.0	16.0	5.6	7.9	20.2	7.2	15.4	54.1	15.7	100.0	16.4	6.6
GR12	Christian	38.1	5.1	4.0	21.6	7.3	4.2	18.5	11.2	4.5	11.1	17.2	5.1	3.0	25.5	5.7	7.7	58.7	17.4	100.0	12.8	5.3
GR14	Montgomery	32.9	4.9	3.4	21.3	5.3	3.4	26.8	10.0	3.5	6.9	16.5	3.7	3.6	25.0	3.6	8.5	57.9	13.2	100.0	12.4	4.3
GR17	Marion	43.8	5.0	3.1	14.6	8.2	3.4	16.6	11.7	3.5	11.3	17.8	3.6	4.0	25.5	4.0	9.7	58.9	7.6	100.0	14.1	3.7
GR18	Washington	52.0	4.7	3.8	14.5	10.0	3.9	11.8	15.5	3.7	8.1	21.3	3.6	5.2	29.5	3.8	8.4	51.9	12.3	100.0	13.3	4.5
GR20	Randolph	58.3	4.6	3.0	13.8	10.8	3.3	7.7	15.1	3.5	6.8	20.8	3.6	2.7	27.5	3.6	10.7	64.0	9.1	100.0	14.3	3.8
GR22	Perry	64.9	5.1	1.0	11.0	12.0	1.0	4.6	15.9	1.1	5.0	20.3	1.2	2.5	29.1	1.4	12.0	59.0	1.9	100.0	14.2	1.1
GR24	Franklin	72.1	3.9	1.0	12.0	11.3	1.2	5.2	16.8	1.2	3.6	21.8	1.3	1.9	31.1	1.7	5.2	58.4	3.7	100.0	9.5	1.2
GR30	Williamson	69.9	4.3	1.7	12.1	11.2	2.0	4.7	16.3	2.1	4.2	22.0	2.2	2.4	29.0	3.0	6.7	59.0	13.3	100.0	10.7	2.6
GF31	Franklin	25.8	2.5	0.6	29.1	6.1	0.6	10.3	13.1	0.6	11.1	20.9	0.6	5.4	31.1	0.6	18.3	61.3	0.7	100.0	19.0	0.6
GF32	Franklin	27.7	2.1	0.6	30.5	6.3	0.6	10.1	12.7	0.6	8.8	21.1	0.8	4.8	30.3	0.9	18.1	65.8	1.0	100.0	19.0	0.8

roof and floor rolls of shale. These rolls are particularly bad in the Danville district.

All of the shale impurities which might be introduced into the coal are usually soft and clayey in the central Illinois and Danville districts, and go into suspension rather easily in water. They are somewhat more firm in the southern part of the Illinois coal basin.

Mineral charcoal is abundant in portions of this coal and by many is considered as an impurity because of its generally higher ash and sulphur content as compared with the other coal constituents. Lenses as much as six inches thick have been observed in some mines. In the samples tested, rough estimates of the amount of mineral charcoal present varied from a low of about one per cent to as much as ten per cent. It is usually friable, and as a consequence is found concentrated in the smallest of the prepared sizes. A simple screening operation to remove material below about 48 mesh will frequently improve the fine sizes, since the mineral charcoal is largely concentrated in the fine dust.

The removable impurities commonly found in this coal bed are pyrite and shale bands, veinlets or flakes of pyrite, calcite and gypsum.

Table 5 gives the data obtained in the float-and-sink analyses in sufficient detail so that complete washability curves can be constructed for the various coals. Table 6 gives the float-and-sink data calculated to selected specific gravities for comparison purposes. It is apparent that a clean, uniform product of low ash content can be produced from most of the coals tested. Only one sample (AA34) gave a sink at 1.60 specific gravity that contained less than 50 per cent ash. The low ash percentage of the sink from this particular sample was due to the presence of large amounts of interstratified particles of pyrite and coal. This sample was retested at 2.0 specific gravity, giving 3.5 per cent of material between 1.60 and 2.0 specific gravities which analyzed 33.0 and 11.7 per cent ash and sulphur, respectively. The 2.0 specific gravity sink was 4.6 per cent of the sample and analyzed 57.1 and 28.9 per cent ash and sulphur, respectively. These data can be used to replace the figures for the 1.60 specific-gravity sink given in the tables by any one desiring to construct washability curves to this higher specific gravity.

There are two areas in which a coal containing less than about 1.2 per cent sulphur is being produced or can be produced, so that, insofar as this impurity is concerned, the coal is suited for most metallurgical or gas-making processes. One of these areas comprises parts of Franklin, Perry, Williamson and Jackson counties. The

Table 6

Comparison Summary of Float-and-Sink Results—Coal Bed No. 6

Per cent by Weight and Per cent Ash and Sulphur in Clean Coal, Middlings, and Refuse
(Moisture Free)

Sample Number	Type of Sample	County	Coal Bed Moisture per cent	Clean Coal <1.40 Sp.Gr.			Middlings 1.40–1.60 Sp.Gr.			Refuse >1.60 Sp.Gr.			Total			Probable Degree of Difficulty of Cleaning at 1.50 Sp.Gr.
				Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	
B3	Channel	Vermilion	14.5*	83.4	7.5	2.0	7.5	25.6	3.6	9.1	56.6	5.6	100.0	13.3	2.4	MD
D5	Channel	Vermilion	14.5*	82.5	6.0	1.0	9.8	22.9	2.1	7.7	66.4	4.2	100.0	12.3	1.3	D
L18	Channel	Stark	16.7	81.5	5.9	3.0	7.5	23.9	5.7	11.0	58.6	16.5	100.0	13.0	4.7	MD
Q24	Channel	Fulton	15.3	89.6	.9	4.3	7.7	17.7	8.0	2.7	58.4	16.2	100.0	10.1	4.9	MD
X31	Channel	Sangamon	13.9	77.7	7.3	4.0	11.3	21.4	5.5	11.0	59.0	22.4	100.0	11.7	4.4	D
AA34	Channel	Christian	11.9	79.3	6.7	4.1	12.6	19.3	6.3	8.1	46.7	21.5	100.0	11.6	5.8	D
AB35	Channel	Macoupin	13.5	76.8	5.8	4.6	13.4	17.9	6.8	9.8	57.9	14.4	100.0	12.5	5.8	D
AB36	Channel	Macoupin	13.5	80.8	5.5	4.3	7.4	20.1	6.1	11.8	63.0	19.2	100.0	13.4	6.2	MD
AC38	Channel	Saline	4.8	89.7	7.4	2.5	6.6	20.4	4.5	3.7	59.7	17.0	100.0	10.2	3.2	MD
AD39	Channel	Gallatin	4.2	80.3	6.8	2.6	7.4	18.7	5.8	12.3	60.1	26.2	100.0	14.2	5.7	MD
AG45	Channel	Franklin	8.2	89.3	4.9	1.1	6.2	24.2	1.5	4.5	65.1	3.6	100.0	8.9	1.2	S
AG46	Channel	Franklin	8.6	90.5	4.9	0.7	4.6	23.4	0.6	4.9	65.6	1.5	100.0	8.7	0.7	S
AO47	Channel	Franklin	9.3	86.0	6.1	0.8	5.3	23.3	1.0	8.7	61.1	3.8	100.0	11.8	1.1	S
AO48	Channel	Franklin	8.6	86.7	5.5	0.8	8.3	24.5	0.8	5.0	59.6	1.7	100.0	9.8	0.8	MD
AH49	Channel	Franklin	8.2	88.7	5.4	1.0	6.0	24.9	1.0	5.3	71.3	1.9	100.0	10.1	1.1	S
AH50	Channel	Franklin	8.8	85.5	5.9	1.1	7.7	24.7	1.8	6.8	63.9	5.1	100.0	11.3	1.4	MD
AJ51	Channel	Jackson	10.1	86.1	6.3	1.1	8.1	23.4	1.3	5.8	58.1	5.0	100.0	10.7	1.4	MD
GR5	Channel	St. Clair	11.1*	79.9	7.1	3.3	9.3	22.4	3.2	10.8	64.1	14.1	100.0	14.7	4.5	D
GR7	Channel	Clinton	12.4*	74.8	6.6	3.7	15.5	18.8	4.4	9.7	50.1	15.0	100.0	12.7	4.9	VD
GR10	Channel	Macoupin	13.3*	62.7	6.8	4.5	21.9	17.5	6.2	15.4	54.1	15.7	100.0	16.4	6.6	ED
GR12	Channel	Christian	12.7*	78.2	7.2	4.2	14.1	19.0	5.2	7.7	58.7	17.4	100.0	12.8	5.3	VD
GR14	Channel	Montgomery	13.3*	81.0	6.7	3.4	10.5	19.4	3.7	8.5	57.9	13.2	100.0	12.4	4.3	D
GR17	Channel	Marion	10.3*	75.0	7.1	3.2	15.3	19.8	3.7	9.7	58.9	7.6	100.0	14.1	3.7	VD
GR18	Channel	Washington	10.1*	78.3	7.3	3.8	13.3	24.5	3.7	8.4	51.9	12.3	100.0	13.3	4.5	D
GR20	Channel	Randolph	10.0*	79.8	6.7	3.1	9.5	22.7	3.6	10.7	64.0	9.1	100.0	14.3	3.8	D
GR22	Channel	Perry	10.3*	80.5	6.7	1.0	7.5	23.2	1.3	12.0	59.0	1.9	100.0	14.2	1.1	MD
GR24	Channel	Franklin	9.4*	89.3	5.6	1.0	5.5	25.0	1.4	5.2	58.4	3.7	100.0	9.5	1.2	S
GR30	Channel	Williamson	6.7*	86.7	5.9	1.7	6.6	24.5	2.5	6.7	59.0	13.3	100.0	10.7	2.6	MD
GF31	Channel	Franklin	8.9	65.2	5.7	0.6	16.5	21.8	0.6	18.3	61.3	0.7	100.0	19.0	0.6	VD
GF32	Channel	Franklin	8.7	68.3	5.6	0.6	13.6	24.2	0.8	18.1	65.8	1.0	100.0	19.0	0.8	D
AL54	2-in. screenings	Christian	12.8	76.7	7.4	3.9	11.3	20.8	6.5	12.0	61.8	16.9	100.0	15.4	5.8	D
AM55	1½-in. screenings	Sangamon	13.9*	79.9	7.5	3.6	7.1	22.5	5.7	13.0	65.6	10.7	100.0	16.1	4.6	MD
F	6-in. x 0-in.	Franklin	9.8	90.5	5.5	0.8	4.8	24.2	0.9	4.4	58.8	1.0	100.0	8.7	0.8	S§
USBM†	¾-in. x 0-in.	Franklin	9.1*	89.9	7.0	1.6	5.3	23.5	2.4	4.8	55.5	15.3	100.0	10.2	2.3	S**
USBM‡	⅜-in. x ¼-in.	Franklin	9.1*	88.3	5.1	1.4	4.9	21.1	3.6	6.8	59.8	10.1	100.0	9.6	2.1	S**
USBM¶	2-in. screenings	Montgomery	13.3*	83.6	8.7	3.8	7.4	23.1	6.6	9.0	57.3	14.2	100.0	14.1	4.9	MD††
USBM¶	2-in. x ¼-in.	Montgomery	13.3*	85.1	9.2	3.8	6.5	24.1	6.9	8.4	56.0	16.9	100.0	14.1	5.1	MD††
USBM¶	3-in. x 2-in.	Montgomery	13.3*	84.6	9.1	4.1	5.8	20.6	7.2	9.6	56.3	20.0	100.0	14.3	5.8	S††
USBM¶	¼-in. x 0-in.	Montgomery	13.3*	76.1	7.1	3.5	9.9	20.2	6.1	14.0	64.3	11.0	100.0	16.4	4.8	D††

*Average obtained from published analyses.
†Egg-size coal crushed to pass a ¾-inch square-hole screen.
‡A screened portion of 1½-inch screenings crushed to pass a ¾-inch square-hole screen.
¶Dust finer than 65 mesh was screened out before the float-and-sink tests were made.
§Bulletin 217, Engineering Experiment Station, University of Illinois.
**Bulletin 300, United States Bureau of Mines.
††Technical Paper 361, United States Bureau of Mines.

other area is much smaller in extent and is located in Vermilion county. In addition, there is a considerable amount of coal located in these same general areas that can be prepared to contain less than 2.0 per cent sulphur.

The remarkable uniformity of the pure coal as shown by the ash analyses for the 1.30 specific-gravity float fractions is observed to extend over several counties with very little variation.

Coal bed No. 6 is called the "Herrin," "Belleville" or "Grape Creek" coal, depending upon the locality where found.

13. *Results Obtained from Coal Bed No. 7.*—The McLeansboro formation which begins at the top of No. 6 coal contains one bed of coal of workable thickness near its base in the northeastern part of the Illinois coal basin. This bed, which is known as the "Danville," "Streator," or "Sparland No. 7" coal, is the same as the "first vein" of the LaSalle district, although it is so irregular as to occurrence and character that correlation between the different mining districts is somewhat doubtful.

This coal is usually of poorer quality than the older coals in the same district. Impurities are irregularly distributed throughout the coal in the form of lenses and irregular bands of pyrite and shale. Bone bands are common and also extremely irregular. Vertical cleavage cracks contain veinlets of pyrite and calcite. In the Sparland district few free impurities are observable, but the coal has a very high content of inherent ash and sulphur, and is of a dark gray color. The data for sample B which is from this district show that cleaned coal at 1.40 specific gravity contains 14.4 per cent ash and 3.3 per cent sulphur.

Coal bed No. 7 varies in thickness from three to seven feet where mined. Rolls in the overlying shales and in the bottom clays are a common occurrence. A considerable amount of roof and floor material usually gets mixed with the coal during mining operations. These intermixed impurities and the irregularly occurring shale bands in the coal proper are soft and go into suspension fairly easily in water, thus complicating the cleaning problem.

This coal bed is only of minor economic importance. The chief production comes from the Danville district. Production from the other districts has almost ceased except that from small local mines.

Table 7 gives the float-and-sink data for the samples tested, and shows that for most of them a product could be produced reasonably low in ash and as low in sulphur as other coals mined in the high

Table 7

Float-and-Sink Results—Coal Bed No. 7

Per cent by Weight and Per cent Ash and Sulphur in Fractions at Different Specific Gravities
(Moisture Free)

Sample Number	County	<1.30 Sp.Gr.			1.30–1.35 Sp.Gr.			1.35–1.40 Sp.Gr.			1.40–1.50 Sp.Gr.			1.50–1.60 Sp.Gr.			>1.60 Sp.Gr.			Total		
		Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S
A1	Vermilion	54.1	4.3	2.6	14.7	10.9	3.2	10.4	16.7	3.3	8.0	21.0	4.1	2.3	29.4	5.4	10.5	57.8	16.8	100.0	14.1	4.4
A2	Vermilion	65.2	4.7	2.6	12.4	12.5	3.0	9.4	17.4	3.0	6.8	23.0	3.5	1.8	33.4	4.2	4.4	52.8	6.4	100.0	10.7	2.9
C4	Vermilion	69.0	5.1	2.8	10.1	9.7	3.5	7.9	15.2	4.4	4.6	22.1	4.5	2.2	29.0	4.8	6.2	56.7	12.8	100.0	10.9	3.7
E6	Vermilion	57.7	4.9	2.9	13.4	10.5	3.6	9.9	14.5	4.4	7.9	20.4	4.7	2.5	27.5	6.8	8.6	62.2	9.6	100.0	13.3	4.0
E7	Vermilion	64.2	5.2	2.8	10.8	11.5	3.2	8.1	16.0	3.3	5.9	22.0	3.6	1.3	31.2	3.6	9.7	68.8	10.6	100.0	14.3	3.7
J2-16	Livingston	60.4	4.9	3.2	13.2	7.7	4.4	8.7	11.7	6.1	6.2	17.5	8.5	2.4	22.8	11.2	9.1	53.6	25.4	100.0	11.5	6.2
AK52	Vermilion	54.1	2.6	2.4	18.3	8.0	3.3	10.8	13.3	3.6	8.5	18.9	3.7	2.3	27.8	4.0	6.0	56.3	6.5	100.0	9.9	3.1
AK53	Vermilion	45.5	2.7	2.4	17.1	8.0	3.3	8.8	13.6	3.6	6.7	18.9	4.6	2.4	27.2	6.9	19.5	57.1	24.0	100.0	16.8	7.2

sulphur areas of the state. The pure coal substance is shown to be very uniform throughout Vermilion county.

Table 8 gives these data calculated to selected specific gravities for comparison purposes. Of the nine samples shown in this table, five present a moderately difficult, and four a difficult cleaning problem. All except sample B from Marshall county could be cleaned to a reasonably low ash percentage.

IV. Summary and Conclusions

14. *Summary.*—Some of the important facts brought out in this investigation relating to the washability of Illinois coal and to the grade of product that could be expected from a mechanical cleaning plant are summarized as follows:

(1) Coal No. 2 is particularly amenable to improvement by mechanical coal cleaning processes. Only one sample was tested that can be classed as very difficult to clean. All of the rest of the samples present either a simple or only moderately difficult problem, as based on specific gravity considerations. The impurities associated with this coal in some localities are soft and clay-like, and would probably complicate the cleaning problem for some types of cleaning plants.

It is possible to produce a coal containing less than 7 per cent ash at practically all mines where samples were taken if the coal is cleaned at 1.40 specific gravity, and a number of samples tested show that a product containing less than 5 per cent ash could be obtained with high recoveries. Coal containing less than 1 per cent sulphur can be prepared from mines operating in parts of Will county, and the coal from parts of Saline, Fulton, Marshall and LaSalle counties need not contain more than 3 per cent sulphur, if cleaned at 1.40 specific gravity.

In general, coal from this bed can be cleaned and put on the market with an impurity content as low as or lower than that of competing coals from without the state. In fact, one area of this bed is exceptionally free of impurities. Sample No. F9 gave a product at 1.40 specific gravity containing only 2.1 per cent ash and 0.6 per cent sulphur, with an indicated recovery of 94.5 per cent.

(2) No. 5 coal shows a variation in degree of difficulty of cleaning from simple to very difficult. Approximately one-third of the samples for which data are given can be classed as presenting simple cleaning problems.

There is a remarkable uniformity in ash content of the 1.30 specific-gravity float fractions for all samples of this coal that were

Table 8

Comparison Summary of Float-and-Sink Results—Coal Bed No. 7

Per cent by Weight and Per cent Ash and Sulphur in Clean Coal, Middlings, and Refuse
(Moisture Free)

Sample Number	Type of Sample	County	Coal Bed Moisture per cent	Clean Coal <1.40 Sp.Gr.			Middlings 1.40–1.60 Sp.Gr.			Refuse >1.60 Sp.Gr.			Total			Probable Degree of Difficulty of Cleaning at 1.50 Sp.Gr.
				Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	Wt.	Ash	S	
A1	Channel	Vermilion	13.0*	79.2	7.2	2.8	10.3	22.9	4.4	10.5	57.8	16.8	100.0	14.1	4.4	D
A2	Channel	Vermilion	13.0*	87.0	7.2	2.7	8.6	25.2	3.6	4.4	52.8	6.4	100.0	10.7	2.9	MD
C4	Channel	Vermilion	13.0*	87.0	6.6	3.0	6.8	24.3	4.6	6.2	56.7	12.8	100.0	10.9	3.7	MD
E6	Channel	Vermilion	13.0*	81.0	7.0	3.2	10.4	22.1	5.2	8.6	62.2	9.6	100.0	13.3	4.0	D
E7	Channel	Vermilion	13.0*	83.1	7.1	2.9	7.2	23.7	3.6	9.7	68.8	10.6	100.0	14.3	3.7	MD
J2-16	Channel	Livingston	12.3	82.3	6.1	3.7	8.6	19.0	9.3	9.1	53.6	25.4	100.0	11.5	6.2	MD
AK52	Channel	Vermilion	13.2	83.2	5.2	2.8	10.8	20.8	3.8	6.0	56.3	6.5	100.0	9.9	3.1	D
AK53	Channel	Vermilion	12.5	71.4	5.3	2.8	9.1	21.1	5.5	19.5	57.1	24.0	100.0	16.8	7.2	MD
B	6-in. x 0-in.	Marshall	15.6	77.1	14.4	3.3	11.5	41.7	5.8	11.4	63.1	17.4	100.0	23.1	5.2	D†

*Average obtained from published analyses.
†Bulletin 217, Engineering Experiment Station, University of Illinois.

tested. With one exception, the ash per cent varied from 3.1 to 5.7 per cent, with nearly three-fourths of the samples containing under 5 per cent ash at this specific gravity. If coal from this bed was cleaned at 1.40 specific gravity a product containing less than 10 per cent ash could be obtained for all but two of the samples tested. Certain samples, particularly those from Saline county, show that the coal from the mines at which these samples were taken could be prepared to contain less than 7 per cent ash and 2 per cent sulphur.

(3) Coal No. 6 varies widely in washability characteristics, even in the same county. For instance, samples from mines in Franklin county show cleaning properties varying from simple to those that would be classed as very difficult. Nevertheless, the ash content of the coal from the lightest specific gravity fractions is very uniform throughout the state. Over 80 per cent of the samples tested gave a product at 1.30 specific gravity which contained 5 per cent or less of ash.

It is evident from the data presented in the comparison summary table for this coal bed that a clean coal containing less than 8 per cent ash is possible at most of the mines sampled; and at a number of mines a clean coal of less than 6 per cent ash could be prepared for the market.

Certain areas of this coal are very low in sulphur. Parts of Franklin, Jackson, Perry, Williamson and Vermilion counties contain coal that is or can be prepared to contain less than 1 per cent sulphur. There is also a considerable area of coal in these same counties that is or can be prepared for market with a sulphur content of less than 2 per cent.

(4) The No. 7 coal is generally not as amenable to mechanical cleaning as coal from the other coal beds. All samples tested indicate a moderately difficult or difficult cleaning problem. However, a low ash coal could be prepared at all mines from which samples were taken in a modern efficient cleaning plant with recoveries ranging from 80 to 90 per cent of the raw coal.

The coal from the 1.30 specific-gravity float fractions is comparable to that from the other coal beds in having a low and uniform ash content over wide areas. If coal from this bed was cleaned at 1.40 specific gravity, a final product could be obtained containing less than 8 per cent ash for all but the one sample from Marshall county. This sample could not be improved enough by mechanical cleaning devices to produce a coal low enough in ash to compete with other coals under present-day market conditions.

All samples tested were high in sulphur, the content varying from 2.9 to 7.2 per cent. Data for two-thirds of these samples indicate that coal cleaned at 1.40 specific gravity would contain three per cent or less of total sulphur.

15. *Conclusions.*—X-ray examination is shown to be a valuable aid in studying the washability characteristics of coal, particularly in illustrating the mode of occurrence and distribution of mineral impurities.

Basing conclusions on theoretical float-and-sink tests only, it is apparent that coal produced from the workable beds of the state is not particularly difficult to clean. Almost two-thirds of the total number of samples for which data are given show either a simple or an only moderately difficult cleaning problem.

Insofar as Illinois coal is at a disadvantage in competition with low ash and sulphur coals from outside the state, it is apparent from the results of the tests herein presented that a low-ash, and at some mines a low-sulphur, coal can be prepared for the market equal to, or better than, any of the imported coals in these respects.

It must not be inferred that coal cleaning is the final answer to all the economic problems of the coal industry. Illinois coal must also be able to compete with imported coals and other fuels on a price basis. Coal in the ground is the raw material of the coal mining industry, and, unlike the conditions in other industries, the operator has no control over the quality of this material but must take it as nature provides it. However, he does have control over the quality of the finished product. He must prepare his coal to meet increasingly stringent demands of consumers, who are insisting on coal of definite specifications as to size and impurity content to satisfy their particular needs. It is the role of coal cleaning to aid the operator in preparing his raw material to meet increasing competition from imported coals of low ash and sulphur content.

Although the results of the numerous tests presented in this bulletin clearly show that coal from practically all of the working mines at which samples were taken can be prepared to meet stringent specifications, yet whether coal from any one mine shall be cleaned or not is largely an economic problem for the mining engineers of the coal company to solve. The primary purpose of this bulletin is mainly to mark the approximate limits of purity that may be attained in cleaning Illinois coals with methods that are now available.